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Ecological service assessment of human-dominated freshwater ecosystem with a case study in Yangzhou Prefecture, China

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Abstract: Freshwater ecosystems provide a host of services to humanity. These services are now rapidly being lost, not least because of the inability of making the impacts measurable. To overcome this obstacle, assessment frameworks for freshwater ecosystem services are needed. A simple water equivalent framework to assess the ecological services provided by freshwater ecosystems was developed in this study. It translated the occupation of freshwater ecosystem services into biologically freshwater volumes and then compares this consumption to the freshwater throughput, that is, the ecological capacity available in this region. In this way, we use the example of Yangzhou Prefecture, to account the main categories of human occupation of water ecosystem services. The result showed that there is a huge gap between the consumption and the supply of freshwater ecosystem services. This must encourage local government to make land-use and water management decisions both economically rational and environmentally sound.

Keywords: freshwater ecosystems; services; human impacts; assessment; water equivalent; Yangzhou Prefecture

Introduction

Sufficient quantities of freshwater have underpinned the advancement of human societies since their beginning. We rely on the solar-powered hydrological cycle not only for water supplies, but also for a wide range of goods and life-support services(Postel, 1997; Dong, 1999). However, our planet's supply of freshwater is finite while demand for fresh water and aquatic ecological goods and services continues to increase as the world's population increases. The sustainable development of Earth's freshwater ecosystems is our only hope to ensure the long-term existence of the fundamentally important benefits that humans derive from freshwater ecosystems.

Since most of the services are easily taken for granted, a myriad of human activities—from the construction of dams, dikes, and levees to uncontrolled pollution—now threaten the freshwater ecosystem services that humanity depends on and benefits from in many ways. Instead of monetary analysis, which is an excellent approach for awareness building but not suitable for pointing to action, identifying ecological limits, or describing competing uses of freshwater services, we developed a simple water equivalent framework to assess the ecological services provided by freshwater ecosystems.

1 Study area and methods

1.1 Basic concepts

Freshwater ecosystem services and the systems that supply them are so interconnected that any classification of the services is necessarily rather arbitrary (Daily, 1997). Here we briefly list the services that rivers, lakes and wetlands provide to the human economy in Table 1.

The total global value of all services and benefits provided by freshwater systems is impossible to measure accurately but would almost certainly measure in the several trillions of dollars (Costanza, 1997). Services provided by freshwater systems in China are valued as 3.5 trillion dollars (Chen, 2000).

Freshwater ecological services interact in different ways. For some services, they are compatible which means the exploitation of one service (such as habitat creation and maintenance) may not impact the delivery of another(such as recreation and entrainment). Some services are competitive, for example, exploitation of one service(such as purification) may impair another (such as water supply and habitat maintenance).

Table 1 Services provided by rivers, lakes and wetlands

Water resource
Supply for household and commercial uses
Evaporation, transpiration and groundwater supply
Hydropower generation
Moderation and stabilization of microclimates
Water environment
Natural purification of wastes
Cycling and movement of nutrients
Transportation
Water habitat
Food and fibre production
Habitat supporting biodiverisities
Water eco-scape
Aesthetic beauty and mental health
Recreation and entertainment
Research and education
Water safety
Moderation of the water cycle
Prevention and control over floods and droughts

Notes: Postel and Carpenter(Postel, 1997) and Ewel(Ewel, 1997)

1.2 Site description

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Our case study area—Yangzhou City lies in the middle part of Jiangsu Province. It covers an area of 6638 km^2 and has a population of 4.47 million. The southern part belongs to the Yangtze River Basin while the northern part to the Huaihe River Basin (Yangzhou Water Resource Annals Compilation Commission, 1999). This area has a subtropical humid-type climate. Annual precipitation ranges from 120—180 cm in rainy years to 40—80 cm in arid years. The precipitation in flood seasons (usually from June to September) accounts for 58% of the total. In flood seasons, most of the rivers and lakes in northern area serve as floodway to evacuate water from the Huaihe River into the Yangtze River while during dry seasons water is diverted from the Yangtze River to mitigate the drought in Huaihe River Basin.

The city enjoys a large area of freshwater ecosystem, which benefits from 46 rivers and lakes, large and small. The total area of surface water(including wetlands) covers 207040 hm^2 accounting for 30.51% of the total. The Yangtze River passes by in the south and the Grand Canal flows through (Yangzhou City Annals Compiling Committee, 1997).

1.3 Analysis on the freshwater ecosystem services in the study area

Many of the freshwater ecosystem services are hidden and easy to take for granted. Widespread ignorance about their importance has promoted their destruction and degradation. A myriad of human activities—from the construction of dams, dikes, and levees to uncontrolled pollution and climate change—now threaten the aquatic ecosystem services that humanity depends on and benefits from in so many ways. The main risks of freshwater ecosystem services in Yangzhou are represented in the following aspects.

1.3.1 Water supply

Human activities impact the water supply service in two general ways. The first affects water quantity by shrinking the storage volume, and the second impairs water quality through the discharge of wastewater.

As a water hub area, Yangzhou has a lot of rivers and lakes. However, freshwater resources are not abundant in this region. The local annual storage capacity of water resource is only 225.0 km^3.

Human demands for fresh water in Yangzhou have increased rapidly in recent decades. Population increase, urbanization, higher living standards and development of industry and agriculture have all contributed to increased water consumption (Wang, 2000). The population in this area has increased by 36 times within approximately 2000 years. Freshwater in this area is used extensively for industrial and domestic needs and for agriculture and livestock production. In 2000, water removed from rivers and lakes in Yangzhou for irrigation, industrial and municipal water supply totaled 263.30 km^3. The gap between water demand and the supply capacity is bridged by diverting water from the Yangtze River. But this affects the water allocation amount for the downstream areas (Fang, 2002).

Removal of excessive freshwater for industrial, agricultural and household use can lower the river level. There is evidence that excessive water diversion makes the flow decrease and the water level lower or even dry (Shi, 1999). No water level records is available in this area, and especially most rivers and lakes are regulated by sluices or dams, making impossible a complete analysis of how the excessive water diversions deplete streamflows and how the water supply service itself degraded. However, some descriptions can still illustrate the trends. Historically, the rivers and lakes in northern part took the Huaihe River as water supplementing source but the supply decrease sharply and even dry over the past decades (Yangzhou Water Resource Annals Compilation Commission, 1999; Fang, 2002).

With the population and consumption growth, pressures to drain more wetlands and divert more water increase. Yangzhou City has lost about 35449 hm^2 of wetlands over the past decades—a 35% loss of the wetland area in 1950's. With the 35449 hm^2 reduction in area of lakes and wetlands, the capacity loss for water storage decreases $5.32 \times 10^8 m^3$ (35449 $hm^2 \times 1.5$ m average water level). During the past two decades, sediment silts 0.5 meter on average in rivers and lakes. This leads to another 10.35×10^8 m^3 (207040 hm^2 $\times$ 0.5 m) loss of water storage ability.

Water quality problem has exacerbated water supply in recent years. We can reveal the deterioration in water quality through describing the changes of intakes of drinking water. In 1960s, people extracted water from the Ancient Grand Canal for drinking. In 1970s, they converted to the Grand Canal and then with the contamination of water in the Grand Canal since 1980s. They diverted water from the Yangtze River in 1990s. Although it does not belong to the water scarcity areas, it is now moving to the water-stress conditions due to the severe water quality problems.

1.3.2 Natural purification of wastes and cycling of nutrients

Under natural conditions, freshwater ecosystem has a self-purification capacity which can, to a certain of extent, decompose, absorb, oxidize/deoxidize, and transfer pollutants and nutrients through complicated physical, chemical and biochemical processes by fauna, flora and microbes. For example, when the nutrient concentration in an aquatic ecosystem is increased by external causes, the production of phytoplankton increases, thus absorbing, converting, storing and decreasing the nutrient concentrations. The production of filter feeders increases with the phytoplankton increment, thus consuming more phytoplankton and decreasing its concentration. A series of interlocking reactions on self-regulation should occur to maintain the relatively stable structure and function of the ecosystem. The ability of self-purification, however, is not unlimited. If pollutants or nutrients load exceeds the tolerance level, or buffering capacity, then the ecosystem's structure and function will be irreversibly changed. As described above, the water self-purification mechanisms can be impaired by alterations of freshwater ecosystem. Physical alteration, water withdrawal, overexploitation, pollution all share the contributions in degradation of water self-purification(Wang, 1988; Yan, 1998).

The artificial regulation of freshwater ecosystems such as sluice construction, embanking and diversion channels totally alters the hydrology structure. It disconnects rivers from their floodplains and wetlands and slow water velocity in riverine systems, converting them to a chain of reservoirs. Now the rivers are almost motionless in most time of the year. The embanking and straightening stops the natural pool-riffle sequence (Erskine, 1992) that creates the hydraulic conditions conducive to hyporheic exchange. Because the sluices are often closed except flood and dry seasons, the requirement for regular flushing flows to prevent the sediments becoming clogged are not met (Schälchi, 1992). Sluices themselves can also act as barriers for the downstream transport of sediment and movement of channel change in up- and downstream directions(Kondolf, 1997; Shields, 2000; Lin, 2001). Sediment is then found to accumulate in rivers and lakes. It can become the inner source to release phosphorus to the water and thus stimulate algal blooms, loss of oxygen, and other problems that affect surface waters. One study recently concluded that sediment makes a great contribution to the eutrophication of Baoying Lake (Yang, 2002). Embankments also contribute the impairment of natural purification service. Embanking intersects riparian vegetation and alters the connectivity of interactions, which can reduce uptake of excess nutrients in surface runoff, increasing nutrient levels in water(Strange, 1999). All these invariably lead to degradation in natural purification and nutrients cycling(Nilsson, 1997; Hancock, 2002).

Wetland can slow down the flow velocity which helps adhesion of toxicant, sediment and removal of suspended particulates. Then nutrients and toxicants are absorbed, stored, fixed or transferred through chemical and biochemical processes by wetland plants and herbage(Dong, 1999; Pu, 2001; He, 2002). With the shrinkage of wetland area, this service to absorb or decompose wastes decreases.

All such alterations reduce the natural purification and cycling and movement of nutrients of freshwater ecosystem. As a result, in 2000, only 41.4% of the surface water in Yangzhou City meets the SEPA (State Environmental Protection Agency) limit of Grade III. Things are worse in those rivers passing through urban areas. The Ancient Grand Canal even exceeds the SEPA limit of Grade V (Yangzhou City Environmental Protection Bureau, 2000). Thus, the service to provide water supply decreases.

Our recent monitoring found that nutrient enrichment of Baoying Lake causes algal blooms and die-offs and decomposition and depletion of dissolved oxygen, water quality degraded from Grade II in 1990 to Grade III in 2001. This lake is now in the mid-stage of eutrophication(Table 2).

Table 2 The nutrition state of Baoying Lake

Item	Annual average	Grade of individual index	Synthesized grade	Nutrition state
Diaphaneity, m	1.625	58		
TN, mg/L	0.86	64		
TP, mg/L	0.027	51	55.6	Mid-stage of entrophication
COD_{Mn}, mg/L	5.32	65		
Chlorophyll-a, mg/m^3	4.09	40		

1.3.3 Fishery production

In 1950s, it was abundant in fishery, with the capture of 14000 t of freshwater fishes from the three lakes. It was recorded that there were about 70 species of fishes in the lakes. But the production decreased to only 500 t in 1960s and 1970s, and about 60% of fish species are facing rapid population decline. Sluice construction and draining of wetland since mid 1950s are the two main causes to this decrease. In this water basin, some fishes usually return back to the Yangtze River for breeding but the sluices sever the breeding ways of these migratory fishes. This leads to drastically reduction in production of such fishes. Some are already extinct. For example, the capture of the migratory eel decreased from 1500—2000 t in 1950s, to 500 t in 1960s and to only 200—300 t in 1970s. Saury, whitebait and other rare species are already extinct. Draining of wetland leads to loss of habitat for some fishes, such as carp and crucian, and thus results in drastically decrease in fish production(Table 3, Nanjing Institute of Geography and Limnology, 1982).

Table 3 Fisheries production from the three lakes in Yangzhou

Year	Production, t	Year	Production, t
1957	14000	1972	5395
1966	4500	1973	5460
1967	5705	1974	6020
1968	7965	1975	6250
1969	6770	1976	6440
1970	5250	1977	4505
1971	5320	1978	3830

1.3.4 Provision and maintenance of habitat

Physical alteration, habitat loss and degradation, water withdrawal, pollution, overexploitation, and the introduction of nonnative species all contribute to declines in freshwater species.

The region has lost 35450 hm^2 of wetland over the past 40 years due to the rural development(mostly filling up the lakes or wetlands for crop plantation). As a result, the key component of aquatic environment has been eliminated and natural plantation conversed to tamed crops. The wild fishes and aquatic plants also deplete because of overharvesting. Dikes and dams construction and heavy pollution destroys hydrologic connection between river, lake and floodplain habitat. Though establishing direct links between human activities and losses of aquatic ecosystem in specific location may be difficult, our monitoring results show that biological community structures in aquatic environment changed greatly.

It is difficult to determine possible changes to fauna and flora in this area due to human impacts because neither historical nor current abundances are well-studied. However, our experimental study in 2001 in Baoying Lake and in one contrast natural site (i.e. comparatively not exploited by human, remaining its natural state) indicated that fauna are in decline. Table 4 and Table 5 reveal the change in species in Baoying Lake.

Table 4 Number of zooplankton in Baoying Lake and the contrast(ind./L)

Site/time	Baoying Lake, 1990 (average)	Baoying Lake, 2001 (average)	Baoying Lake, Sep., 2001	Contrast, Sep., 2001
Cladocera	2.01	0.64	0.88	
Copepoda	3.68	3.12	2.38	
Rotifer	12.3	8.83	6.63	
Protozoan	—	3.15	3.21	
Other species		0.10	0.34	
Total	17.99	15.84	13.44	50.5
H'		0.476	0.501	1.687

Note: *H'* is the Shannon-Wiever biodiversity index

Table 5 Number of benthic invertebrates in Baoying Lake and the contrast (ind./m²)

Site/time	Baoying Lake, 1990 (average)	Baoying Lake, 2001 (average)	Baoying Lake, Sep., 2001	Contrast, Sep., 2001
LamelliBranch (*Unionidae*)	30.0	9.9	1.3	32
GastroPoda (*Viviparidae*)	180.0	91.1	53.3	1712
Crustacea (*Palaeminidae*)	11.0	10.2	6.7	
Insecta (*Chironomidae*)	81.1	5.0	1.3	1014
Polychaeta (*Branchiura sowerbyi* (Beddard))	53.5	5.0	0	16
Total	355.7	119.9	62.7	2092

At the same time, the composition of vascular bundle plants changes greatly over the past years due to aquaculture and other activities. In the purse-net aquaculture area in Baoying Lake, the simplification process of aquatic plants is very clear. Due to the crab breeding, *Ceratophyllum demersum* L. and *Hydrilla verticillata* Royle are almost used up by the main predator, the crabs, but *Myriophyllum verticillatum* L. and *Vallisneria spiralis* L. remains. *Myriophyllum verticillatum* L. approximately takes up 80% of the total advanced aquatic plant biomass, forming single plant community. The biodiversity of aquatic plants in Baoying Lake thus declines.

Due to large-scale exploitation of riparian wetlands, original wetland ecosystems, e.g. *Phragmites communis* Trin., *Zizania caduciflora kuntze*, *Typha angustifolia* Linn. degrade.

1.3.5 Prevention and control over floods and droughts

Agriculture is the major source of the silt and fine sediments. Normally, the input of sediments from instream keeps balance with the losses from flushing or extraction. But, since so many sluices and dams have been constructed to control over floods and droughts, the balance is broken because the flow velocity have been slowed down and high flows reduced. Thus, there is little down-welling water to flush out silt. Also, sluices and dams often act as barriers for the downstream transport of sediment. In early years, farmers in this area used to dig out the sludge from the river or lake beds as fertilizers. But now they prefer to chemical fertilizers. Accumulations of sediment lead to channel instability and a decrease in storage, enhancing the frequency of floods and reducing the alleviation over droughts. Wetlands, the porous sediments in banks adjacent to streams can act as buffers to rising water levels and reduce, delay, or even prevent the occurrence of flooding (Dong, 1999; He, 2002). But draining of the wetlands, embanking and other activities impair this ability. Increased impermeable areas due to urban sprawl raise the volume of runoff. Due to silting of sediments, the depth of main rivers and lakes in Yangzhou City decreases 0.5 meter over the past 20 years (Yangzhou City Annals Compiling Committee, 1997). This leads to the loss of 5.24×10^8 m^3 of storage (0.5 m × 51910 hm^2 of river + 0.5 m × 52850 hm^2 of lake). The regulation over floods is in decline. The frequency of flooding in this area was only once every 3—4 years from 1644 to 1911, while in the most recent five decades, more than 30 floods have occurred (Yangzhou City Annals Compiling Committee, 1997).

1.4 Methods to measure freshwater eco-services

Human life and all human activities depend so heavily on freshwater ecosystems. Without it land-based life as we know would disappear. Unlike oil, coal, or tin, for which substitutes exist, freshwater is largely nonsubstitutable. The implication of this ecological maxim is obvious: to be sustainable, humanity must live within nature's carrying capacity.

Sustainability has now become a universal policy goal. However, humanity is further away from sustainability. To make sustainability a reality, we must measure where we are now and how far we need to go. We need measuring tools to determine whether humanity's demand remains within the interests of the natural capital stocks (Wackernagel, 1999).

Environmental economists have developed a variety of techniques for measuring ecosystem services. Valuation methods have been prominent in recent discussions because they are being used in legal efforts to protect and restore ecosystems (Portney, 1994). Many of these studies try to estimate the total economic value of ecosystem services, both global and local (Costanza, 1997; Chen, 2000; Colby, 1989; Ehrenfeld, 2000; Brouwer, 1999). Such methods also seem to be a promising way to include ecological values when various public policies and projects are under consideration. Economic valuations may have quite perverse and pernicious effects unless they are applied with a careful regard for their limitations.

Such methods work well for small projects of minor importance, or possibly for fine-tuning of larger projects. But these methods—and economic methods in general—are inappropriate and harmful when used to determine important public policies(Ludwig, 2000).

To translate the strong sustainability criterion into concrete numbers and to examine whether society lives within its ecological capacity, a first overview needs to account for freshwater resource and its uses. As ecological services are a precondition for human life rather that a substitutable value, this resource accounting needs to be in biophysical units (Wackernagel, 1999). This study presents a simple framework for the assessment of freshwater ecosystem services. Enlightened by the concept of footprint developed by Mathis Wackernagel and his colleagues, we try to use the simple concept of "water equivalent" to assess the freshwater ecosystem services.

As demonstrated in this study and explained through the example of Yangzhou, the water equivalent concept offers a methodologically simple but comprehensive way for such an accounting task. The water equivalent represents the critical freshwater ecosystem services of a defined economy or population in terms of the corresponding freshwater resource volume. It translates the occupation of freshwater eco-services into biologically freshwater volumes and then compares this consumption to the freshwater throughput, that is, the ecological capacity available in this region. Some regions claim more freshwater capacity than the local throughput. This means that they run an ecological deficit. Consequently, they need to import their missing ecological capacity—or deplete their local freshwater stocks. Regions with water equivalent smaller than their capacity are living within their own freshwater means. Often, however, the remaining capacity is used for producing export goods rather than keeping it as a reserve(Wackernagel, 1999).

2 Results and discussion

The results obtained by the above-described water equivalent analysis are briefly presented. Also, limitations and flaws of this tool are discussed.

2.1 Freshwater consumption

Express freshwater consumption for industrial, agricultural and household uses into water equivalent.

In 2000, the total water consumption is 26.33×10^8 m^3, thus the water resource consumption scores as 26.33×10^8 m^3.

2.2 Waste purification

Freshwater remaining in its natural channels helps keep water quality parameters at levels safe for fish, other aquatic organisms, and people. To translate the purification service into water equivalent, the basic assumption is: this service remains the highest if not any pollutants are discharged to waterbodies by humanity. The very intense human activities can reduce this service to zero or even negative. Clean water should be diverted from the outside and large sums should be spent to restore and protect water quality. Based on this idea, we develop a simple methodology to measure the consumption or contribution of human production and life to water eco-services. The old adage "Dilution is the solution to pollution" described the basic approach to pollution control up until about 1970. Dilution alone is certainly not sufficient to protect water quality. The decontamination services are realized through a very complicated process of physical, chemical, biological and microbiological interactions. But without the dilution function, things would be much worse. Virtually all countries, however, still depend heavily upon the dilution capacity of natural waters. Even in the OECD countries, domestic wastewater treatment is estimated to cover only about 60 percent of the population(Biswas, 1992). In this sense, occupation of purification services can be estimated through proxy calculations, for example, by estimating how much clean water needed to dilute the wastes' concentration in water to the national water quality standard. We assume that Grade III of water quality still have full value of purification.

According to the actual waste discharge, key pollutant parameters should be selected. For industrial and domestic wastewater, COD is determined as the key factor, while for non-point pollution from farming activities and from run-off over city areas, nitrogen and phosphorus are key factors (Zhang, 1997).

2.3 Provision of habitat

Not all the biological capacity is available to human use as freshwater ecosystem should provide habitat for the fellow species. According to the World Commission on Environment and Development, at least 12% of the ecological capacity, representing all ecosystem types, should be preserved for biodiversity protection(WCED, 1987). This 12% share is most likely insufficient for securing biodiversity(Noss, 1991; 1994), but conserving more may be politically unfeasible. By accepting 12% as the magic number for biodiversity preservation(Wackernagel, 1999), for the purpose of the calculations presented here, it follows that from the 679.0 km^3 of water resource volume in Yangzhou, only 597.5 km^3 is available for human use. These 597.5 km^3 become the ecological benchmark figure for comparing people's water equivalent. Therefore, the current population numbers, the challenge to Yangzhou is to reduce the water equivalent to at least this size.

2.4 Droughts and floods regulation capacity

Lakes and wetlands area have shrunk from 1033.19 km^2 in 1970s to today's 678.70 km^2. The deposit loss of water resources is over 0.53 km^3. The regulation capacity for droughts and floods decreases by 0.35 km^3.

Due to silting, the regulative capacity of lakes and rivers diminishes 0.52 km^3.

Table 6 shows the freshwater resource available in Yangzhou is only 679.0 km^3. Taking phosphorus as the key water parameter, the water equivalent is 4.96 times larger than the ecological carrying capacity of the freshwater ecosystems in Yangzhou while taking nitrogen as the key factor, it exceeds 3.07 times of the capacity available. It means that there is a huge gap between the consumption and the supply. Large amount of water should be borrowed from other places, which means great pressure to other regions in the lower streams of the Yangtze River.

Table 6 Occupation of freshwater ecosystem services in Yangzhou

Categories	Human activity	Pressures to aquatic environment	Occupation of services in water equivalent	
Use of water resource	Agriculture	23.36 × 10^8 m^3	26.33 × $10^8 m^3$	
	Industry	1.54 × $10^8 m^3$		
	Urban and rural household	1.43 × $10^8 m^3$		
Water purification	Industry	COD 12302.57 t	17.97 × $10^8 m^3$	
	Urban household	COD 23630.7 t		
			N	P
	Chemical fertilization	N 42698 t		
		P 12599 t	223.4 × $10^8 m^3$	352.0 × $10^8 m^3$
	Aquaculture	N 7733 t		
		P 1559 t		
	Livestock husbandry	N 2432 t		
		P 1107 t		
Provision of habitat	Securing biodiversity	12% of the ecological capacity	8.15 × $10^8 m^3$	
Droughts and floods regulation capacity	Water area shrinking	354.49 km^2 lost over 35 years	0.51 × $10^8 m^3$	
	Filling-up of rivers and lakes	0.5 m shallowed over 20 years		
Total			276.4 × $10^8 m^3$	405.0 × $10^8 m^3$

3 Conclusions

These calculations give us an amount of the freshwater ecological capacity consumed and available for Yangzhou. They provide us therefore with information of both the stocks and the flows it produces.

This water equivalent framework offers a cheap and rapid appraisal for regions with which human demands can be compared with the freshwater available supply for human use. The water equivalent is an accounting tool that can aggregate ecological consumption in an ecologically meaningful way. It gives us, therefore, a realistic picture of where we are in ecological terms. This is what we need to know to achieve sustainable development (Wackernagel, 1999). The assessment allows us to direct attention to the magnitude of human's use of freshwater eco-services and thus it's useful and helpful for providing a context for tangible action (Robins, 1995), identifying ecological limits, or describing competing uses of these services.

Two complementary strategies can reduce water prints while not compromising our quality of life. (1) Restore freshwater eco-services through positive ecological construction, such as improving the efficiency of water use, develop water-saving equipment and applying all sorts of water-saving technologies, improving wastewater treatment ratio, recycling wastewater and removing silt from lakes and rivers and thus enlarging water surface area and so on. (2) Consume less by being fewer people and consuming less per capita, e.g. by avoiding expensive life-style which may buy people more leisure time and be less harsh on their health (Dominguez, 1992). Currently, we are working on a project of water eco-construction in Yangzhou. Through some concrete actions we suggest, human consumption of water eco-services can be greatly reduced.

Without any doubt, there exist still many limitations with the calculations presented in this study. Methodologically, the assessment could be made more complete by including the occupation of other water eco-services, e.g. transportation, recreation, soil fertilization and so on, but we do not do it here. Calculations on these services may be more difficult—or in some cases even impossible—to accurately represent within the water equivalent framework. The inclusion of all possible aspects of ecological impact into water equivalent assessments may lead to levels of sophistication that miss the main purpose of this tool: providing a big picture analysis to put the various competing human uses of freshwater ecosystems in each other's context (Wackernagel, 1999).

Moreover, ideally, we should use water equivalent volumes with world average water eco-service as a common measurement unit for water equivalents and ecological capacity. Using a common standard could make national or regional water equivalents comparable. Also, we should subtract from such figures the water resources that are embodied in exported finished products while including that are processed for export goods. Thus the water equivalent per capita in stead of the total water equivalent of a nation or a region can be figured out. It would make more sense because water equivalents in different nations or regions are then comparable. But we do not do that here. One big limitation is the data source. It is more difficult to differentiate imports and exports from all finished products within a region than within a nation because our statistical system does not represent the goods imported from or exported to other regions within the country. Another big obstacle is the common measurement because water equivalent of world average is much more difficult to determine than "biological productive areas with world average productivity" developed by Wackernagel and his colleagues. However, we are making our efforts to do this currently in one of our projects.

Nevertheless, the presented simple calculation framework becomes a starting point for more complete and more accurate accounting of freshwater eco-services. As such accounts can be summarized in a single number, they may prove to be an easy-to-read measurement tool for sustainability of freshwater ecosystems. Much additional research is needed to establish the intricate connections between human activities and the loss of freshwater ecosystem services and to present a perfect framework to assess humanity's impacts on freshwater eco-services.

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